Renewable and Sustainable Energy Reviews 40 (2014) 716–726

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Jet biofuels in Brazil: Sustainability challenges

Marcia A.F.D. Moraes [a,*], Andre M. Nassar [b], Paula Moura [b], Rodrigo L.V. Leal [c], L.A.B. Cortez [d]

[a] University of Sao Paulo (USP), Luiz de Queiroz College of Agriculture, Avenida Padua Dias, 11, Piracicaba, 13416-480, SP, Brazil
[b] Instituto de Estudos do Comércio e Negociações Internacionais (ICONE), Avenida General Furtado Nascimento, 740 conjunto 81, São Paulo 05465-070, SP, Brazil
[c] University of Campinas (UNICAMP), Campus Universitario Zeferino Vaz SN—Cidade Universitaria, Campinas 13083-970, SP, Brazil
[d] University of Campinas (UNICAMP), Faculty of Agricultural Engineering, Campinas 13083-970, Brazil

ARTICLE INFO

Article history:
Received 16 August 2013
Received in revised form
11 June 2014
Accepted 31 July 2014

Keywords:
Aviation biofuels
Roadmap
Sustainability
Biofuel feedstock

ABSTRACT

Sustainability is a fundamental topic to be addressed in the establishment of a market for jet biofuels in Brazil. The objective of this paper is to enhance the discussion on sustainability of biofuels, and to discuss the main gaps to meet the requirements of sustainability for four groups of feedstock: sugars and starch, oil, lignocelluloses, and wastes. Some general common conclusions can be made for all the analyzed feedstock. In the social sphere, the main positive impacts are the high potential for job creation, income generation and regional development. Regarding the gaps for compliance with sustainability requirements, the following aspects were common to all groups of feedstock: great number of laws and rules; different interpretations and lack of knowledge on how to apply some laws; certain labor laws not adapted to the rural context. The main potential positive impact generated by compliance with requirements is greenhouse gas (GHG) emissions reductions compared to fossil fuels.

Contents

Abbreviations: (HCVA), high conservation value areas; (LUC), land use change; (ILUC), indirect land use change; (ISCC), international sustainability and carbon certification; (RSB), Roundtable on Sustainable Biomaterials; (NR), regulatory norm; (GHG), greenhouse gas; (GMO), genetically modified organisms; (MSW), municipal solid waste

* Corresponding author. Tel.: +55 19 3429 4444.
E-mail addresses: mafdmora@usp.br (M.A.F.D. Moraes), amnassar@agroicone.com.br (A.M. Nassar), paulatmoura@gmail.com (P. Moura), rvleal@ig.com.br (R.L.V. Leal), labarbosacortez@gmail.com (L.A.B. Cortez).

http://dx.doi.org/10.1016/j.rser.2014.07.210
1364-0321/

1. Introduction

This paper aims to enhance the discussion on sustainability of biofuels for aviation, related to environmental, social, economic, and institutional aspects existent in Brazil.[1] Sustainability assessment has been growing in importance in recent years, especially in a scenario including the need for reduction of greenhouse gases emissions, the food versus fuel debate, and the increasing need to respect environmental and social standards.

The global concern with climate change, combined to the world dependence on fossil fuels, higher price volatility and the increasing uncertainties on oil supply have motivated a growing interest for renewable energy sources, particularly in the form of biofuels. This can be extended to the aviation sector, which has few alternatives to the conventional fuel due to its dependence on liquid fuels with high energy density [1,2].

According to IPCC [3], estimates of CO_2 emissions from global aviation increased by a factor of about 1.5, from 330 $MtCO_2$/yr in 1990 to 480 $MtCO_2$/yr in 2000, and accounted for about 2% of total anthropogenic CO_2 emissions. Since aviation CO_2 emissions are projected to continue to grow strongly, the use of biofuels has been encouraged, as a way to reduce the impacts on the climate. Sgouridis [2] argues that pricing (as a form of demand rationalization) or renewable fuels are the only alternatives towards a more sustainable aviation industry considering that other options, such as efficiency improvement and electrification are either already being pursued or not feasible.

The main targets of the aviation industry worldwide in order to mitigate GHG emissions are to achieve Carbon Neutral Growth from 2020 and beyond and to reduce by 50% net CO_2 emissions by 2050 over 2005 levels [4].

Considering that second generation biofuels for aviation, such as hydrogen using solar power and electrolysis, are far from being a reality, kerosene derived from biological sources remains the most viable currently available technology for the aviation industry [2]. In this context, the most promising potential feedstock for jet biofuel are plants that contain sugars, starch, and oil, as well as residues such as lignocellulose, municipal solid wastes, and industrial waste residues. However, these feedstock are constantly under the spotlight when it comes to sustainability issues [1,2,5]. Such controversy is directly related to agriculture and agricultural practices and has been highlighted since biofuels started being developed. According to Sgouridis [2]:

Perhaps the most critical driver in the adoption of biofuels as sustainable aviation fuel is the ability to demonstrate convincingly that they are indeed sustainable.

Brazil is the world's largest producer of sugarcane (the country is internationally recognized for its long experience of using biomass for energy purposes beginning with wood, sugarcane ethanol), second of soybeans and has the lowest production cost of eucalyptus; therefore, Brazil can competitively produce the above listed classes of feedstock, which could be used to start a jet biofuel industry in the country. In addition, sugarcane and eucalyptus can be produced with a very significant life-cycle reduction of CO_2 emissions [6].

The availability of feedstocks for biofuels, in terms of both production quantities and diverse sources, is not a major concern in Brazil [7–10].

According Flight Path to Aviation Biofuels in Brazil: Action Plan [6], most of the crops in Brazil are rain-fed and do not require irrigation. The extensive Brazilian territory has areas of temperate, subtropical and tropical climates, which allow the cultivation of different crops suitable for jet biofuel. In contrast to some regions in the world that are adopting biofuels based on agricultural products, evidence in Brazil shows that the agricultural sector has been able to meet the increasing demand of both food and energy.

ILUC and food versus fuel are the two most relevant indirect effects raised as concerns in the biofuels debate. Ludeke-Freund et al. [5] provide a literature review of the major sustainability issues and accounting challenges for the production of biomass-based jet fuels focusing primarily on plant oils. The authors put into question the methods used for assessing sustainability of biofuels, including those of private standards, such as the RSB and suggest two new concepts for assessing the sustainability of feedstock production for biofuels. They conclude by emphasizing the importance of taking into account the complex challenges of sustainable agriculture in the process of developing and adopting jet biofuels.

Tilman et al. [11] suggest that there are five groups of feedstock that have significantly lower lifecycle emissions when compared to fossil fuels and that do not compete with food: (1) Perennial plants grown on degraded lands abandoned from agricultural use; (2) Crop residues; (3) Sustainably harvested wood and forest residues; (4) Double crops and mixed cropping Systems; and (5) Municipal and industrial wastes. This shows that the potential feedstock suggested in this study are aligned with the sustainable pathway. Furthermore, as will be discussed in detail, Brazil has a favorable position to support the establishment of a sustainable jet biofuel industry.

Evidence indicates that the expansion of cane ethanol in Brazil has not undermined food production. The same evidence also shows that concerns regarding a direct causal relationship between ethanol expansion and native land conversion are not supported in reality. The evidence is based on the following facts: (i) Brazilian agriculture is facing a process of intensification and efficiency gains with increasing yields in crops and livestock; (ii) there still is a lot of space for intensifying cattle production in Brazil; (iii) Brazil has developed a double-cropping system allowing the integration of soybean and corn in the same year; (iv) the

[1] This research was conducted during the year of 2012, under the project named "Sustainable Aviation Biofuels for Brazil". The project was funded by Boeing, Embraer, FAPESP and several other sponsors. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the funding parties, including The Boeing Company and Embraer S.A. The authors acknowledge the important contributions of the sponsors and of the project members (researchers, administrative team and consultants).

expansion of sugarcane for ethanol, although very strong, has not undermined the expansion of other annual and perennial crops. Therefore, rather than food-versus-fuel, the reality in Brazil shows a food-and-fuel situation; the cultivation of oilseeds in rotation with sugarcane is also generating food and fuel in the same systems; deforestation has been reduced since 2004 [6].

Brazilian laws are quite strict to protect natural resources, water and biodiversity. Brazilian legislation establishes that at least 20% of the land of individual farms (50% to 80% in the Amazon region) be set aside under Legal Reserve in order to preserve natural resources, water sources, biodiversity, and shelter for the native fauna and vegetation. In addition, stretches of land along water bodies as well as those with slopes above 45° are Areas of Permanent Preservation and cannot be legally converted to production. The Brazilian Forest Code is among the most restrictive legislation on land use. Labor laws are equally severe.

However, not all bioenergy is sustainable energy. Biofuels shall be developed using strong sustainability criteria and verification to meet the needs of the aviation industry [2]. The aviation industry will most likely require a sustainability certification for jet biofuels, in order to guarantee that such fuels are produced in compliance with environmental and social requirements determined through a multi-stakeholder process.

Bauen et al. [12] review the potential for aviation biofuels according to technical suitability, fuel requirements, economic aspects and sustainability issues. The authors analyze sustainability benefits and constraints taking into consideration the principles of the UK Renewable Transport Fuel Obligation in five different groups of feedstock: (1) Energy Crops; (2) Residues and wastes; (3) Conventional oil crops; (4) New oil crops (jatropha and camelina); and (5) Algae. They conclude that sustainability aspects can limit potential in the long run and that the impacts of each group of feedstock will vary depending on the collection and production practices, as well as on competition with other uses. However, they classify the five groups of feedstock by likelihood of impact, reaching the following result: (1) Energy Crops: mid-low; (2) Residues and wastes: low; (3) Conventional oil crops: high; (4) New oil crops: mid-low; and (5) Algae: low.

Considering this, the objective of this paper is to enhance the discussion on aspects of sustainability of biofuels for aviation in Brazil, and to identify and discuss the main gaps to meet the requirements of sustainability for four groups of feedstock: sugars and starch, oil, lignocelluloses, and wastes. Also, we aim to identify the impacts of the compliance of the criteria of the most known international sustainability standards for biofuels production (such as Bonsucro, the Roundtable on Sustainable Biomaterials (RSB) and international sustainability and carbon certification (ISCC), on financial, technical and commercial risks for these supply chains.

These sustainability certifications are focused especially on GHG emissions reductions, other environmental impacts (such as water and biodiversity), and minimization of socio-economic impacts. These standards are generally similar in terms of principles and criteria. They all require compliance with the national law and relevant international conventions and have many criteria that are already covered by the Brazilian law.

Broadly, the most different criteria are related to indirect impacts, such as food security, indirect land use changes (ILUC) and biodiversity. These additional criteria are associated to complex issues that are still being extensively discussed. There are no widely accepted methodologies to address them, which complicates even more their inclusion into the standards. This results in the inclusion of such issues in the standards in a very conservative manner and in the involvement of the standard initiatives in the related methodological and scientific discussions.

Therefore, it is important to discuss these issues, since sustainability certifications will increasingly become a requirement for accessing markets and since the standards and certifications processes are complex and require adaptations of the supply chains. While they may generate benefits for producers and processors, they may also generate additional costs and hurdles. It is fundamental to understand the differences between the standards and the gaps to compliance when considering the context and opportunities for jet biofuel production in Brazil.

2. Material and methods

The roadmapping methodology implemented in the broader research project[2] – Sustainable Aviation Biofuels for Brazil – was aimed at reaching a consensus on action plan priorities in order to promote the use of sustainable biofuels for aviation. The methodology was constructed using workshops to stimulate the discussions among the stakeholders.

This research is based on the Sustainability Workshop, which aimed to stimulate the discussions on sustainability aspects for four groups of feedstock (sugars and starch, oil, lignocelluloses, and wastes), with the stakeholders of the broader research project.

The first day of the sustainability workshop was divided into sections according to the three pillars of sustainability (economic, social and environment), as well as a section focused on the sustainability standards. The sections on the sustainability pillars had three speakers, being one from the academy, one from the productive sector and another one from an NGO.

On the second day the stakeholders were divided into four groups, according to the feedstock groups—sugars and starch, oil, lignocelluloses, and wastes. Each group discussed and filled out a spreadsheet in order to identify, for each sustainability requirement, the compliance gaps and the impact of the sustainability requirement on the following dimension: Technical (related to the production process), Financial (related to the monetary resources required) and Commercial (related to market issues).

Each sustainability requirement was explained to the stakeholders in the groups, who were then asked to give their opinion on the compliance gaps and on the impact of the requirements on the above-mentioned dimensions. The sustainability requirements analyzed will be presented in detail in the next section.

The first discussion of the group section aimed to assess how difficult it is to *be compliant* (or keep being compliant) with each sustainability requirement. The participants had to choose which alternative they considered most appropriate for each requirement: (i) easily compliant; (ii) compliant with only few difficulties; (iii) compliant with great difficulties; (iv) very hard to be compliant; (v) neutral or irrelevant or not applicable.

As for the impact of the sustainability requirement on each dimension, we aimed to identify:

- *Technical impacts*: If the sustainability requirement will have positive or negative impacts on the level of technical risks the economic agents operate with today i.e.: technical complexity, need for new or external technologies and/or qualified personnel, new processes impacting production capacity.
- *Financial impacts*: If the sustainability requirement will have positive or negative impacts on the Business Plan the economic agents have today

[2] Sustainable Aviation Biofuels for Brazil Project, sponsored by Fapesp, Boeing, Embraer. The project team conducted eight workshops across Brazil, including São Paulo, Rio, Minas Gerais and Brasilia, with active participation of over 30 Stakeholders encompassing the entire prospective aviation biofuel supply chain, including industry, agriculture, government, NGOs and academia. The assessment covered feedstock production and delivery, conversion technology, fuel delivery logistics, sustainability and policies.

i.e.: investment (capital expenses and operational expenses), profit margins, payback period.

- *Commercial impacts*: If the sustainability requirement will have positive or negative impacts on the level of commercial risks the economic agents operate today i.e.: meeting customer demands, modification on channels, and access to raw materials or other essential components supply.

3. Theoretical framework

Accounting for the sustainability effects of biomass production is a challenge, which has been undertaken increasingly in the last 30 years. It is clear in the literature that most of the work follows the principles of sustainable development.

According to Del Rio and Burgillo [13], Sustainable Development (SD) has traditionally been defined as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. However, the authors emphasize that this definition does not allow an assessment of whether a given development proposal is sustainable, and it is important to have a more dynamic approach to sustainability, which is adapted to the regional or local territorial contexts. The authors developed an integrated theoretical framework to assess the impact of renewable energy on local sustainability, considering the distinction between the two interrelated sustainability approaches – procedural and substantive – when analyzing the impacts of renewable energy deployment on local sustainability. According to the authors, the following aspects must be considered: (1) the Impact on the three dimensions of sustainability (economic, social and environmental); (2) Perceptions of local stakeholders. With this, it is important to consider the different local stakeholders and the economic, social and political relationships between them.

The sustainable development concept became widely used after it was defined by the Brundtland Commission of the World Commission on Environment and Development (WCED). It is based on the notion of defining principles, criteria and indicators that take into account all aspects of the sustainability triple bottom line: economic, social and environment [2,5,13,14]. Therefore, the definition and/or adoption of sustainability criteria relevant to the specific biomass being studied, and the stakeholder's perception were the chosen theoretical framework [2,5,13].

The assessment on the sustainability criteria for the production of feedstock in Brazil was carried out according to the principles stated in Goldemberg [15] and also considering the principles and criteria of the currently available and most well-known sustainability standards. To assess the most relevant standards, this research took advantage of a recent report released by Nassar et al. [16]. The authors carried out a benchmark to assess the main differences between three standards for certification of biofuels (Bonsucro, RSB, and ISCC) and to identify the main gaps for compliance with these standards in Brazil. Although the study was focused on a jet biofuel produced from sugarcane, many of the issues identified are common to the whole agricultural sector in the country. Compliance with the national law, especially environmental, labor and worker health and safety is one of them. There are other gaps that go beyond the law, especially related to the interpretation and implementation of certain criteria, such as high conservation value areas (HCVA), ILUC and food security. The requirements of these criteria are not clear and there is uncertainty regarding how they will be implemented in Brazil.

The analysis included, although was not limited to, the evaluation of some parameters (when data was available): energy balance; greenhouse gases emissions; agricultural productivity; agricultural and environmental best practices: fertilizer consumption, consumption of pesticides, soil loss, water use; biodiversity; energy self-sufficiency; social, economic, institutional environment aspects: legislation, regulations.

The Sustainability requirements analyzed were:

- *Laws and international conventions*: Compliance with relevant national laws and international conventions;
- *Land rights*: Having official documents to prove title to land or right to use land;
- *Employment, wages and labor conditions*: Compliance with laws and regulations related to wages, working hours, breaks, overtime and formal contracts. Rights to organize, complaints and communication mechanisms (labor unions, etc.);
- *Human health and safety*: Comply with regulations and standards related to conditions of occupational safety and health for workers (Example: NR-31);
- *GHG emissions*: Emissions reduction potential and calculations. Different requirements for each standard;
- *Biodiversity and ecosystems*: No negative impacts on biodiversity and ecosystems;
- *Soil*: Soil conservation, maintaining soil health and reversing soil degradation (example: erosion);
- *Water*: Maintaining or enhancing the quantity and quality of groundwater and respecting formal and customary water rights;
- *Air*: Mitigation of air pollution and limitations/restrictions on open air burning as part of the production cycle;
- *Waste*: Reduction, treatment and disposal of waste to avoid environmental contamination;
- *Crop management and agrochemical use*: To use best practices of storage, handling and disposal of fertilizer and agrochemicals; application rates; Use of integrated pest management systems and other non-chemical systems;
- *Direct land use changes*: Restrictions related to the conversion of areas considered to have high conservation value, which can include degraded pasture areas (the requirements vary among the standards and the European Union has not yet defined maps of high conservation areas);
- *Social and environmental impact assessment*: Preparation or existence of official document specifying how social and environmental impacts of operations are identifies, monitored and mitigated;
- *Rural and social development*: Provision of social benefits to employees and social surroundings and implementation of actions to promote social development and improvement of socioeconomic status of local stakeholders. Plus assessing and mitigating negative impacts on communities and groups (women, youth, children and indigenous communities);
- *Contractors and suppliers*: Existence of requirements for contractors and suppliers to comply with human rights and labor standards;
- *Engagement and communications with stakeholders*: Existence of requirements in the context of implementing processes or structures (governance) to guarantee multiple and relevant stakeholder participation throughout stakeholder consultation phases and certification process;
- *Economic viability and production and processing efficiency*: Using all resources efficiently, using less inputs to generate more outputs. Promoting long term economic viability of business;
- *Food security*: Assessing the impacts that biofuel production/processing may have on the production, availability, prices, of food. Producers and processors may be using food or land for biofuels that could be used to grow food for local communities.

4. Main results

The results are presented by feedstock group: sugars and starch, oil, lignocelluloses, and wastes. The option for focusing

the analysis of the sustainability gaps and impacts on the feedstock itself, rather than the industrial process, is justified because the main sustainability gaps and impacts reported by the stakeholders were related to feedstock production. Furthermore, with the exception of GHG emissions, which is related to the entire production process, all parameters used by the sustainability standards are directly related to the feedstock's production. The results are presented according to the compliance gaps and impacts on the three dimensions.

4.1. Sugars and starch

4.1.1. Sustainability gaps

Considering the 16 requirements[3] analyzed by the stakeholders in the sucrose group discussion, it was observed that the great majority of the requirements were considered in the category "compliant with only few difficulties"; two of them were considered to be "easily compliant"; three of them "compliant with great difficulties", and one "very hard to be compliant".

The most difficult requirement to be accomplished was considered the need for contractors and suppliers to comply with the labor and environmental norms. There is a consensus among the stakeholders that major compliance difficulty is related to sugarcane independent suppliers, which shall also be compliant with the requirements[4]. Besides the difficulty with the contractors and suppliers, the main compliance difficulties were related to: (i) *national laws and regulations*; (ii) *biodiversity and ecosystem*; (iii) *crop management and agrochemical use*.

As regards *international laws and international conventions* and laws governing pesticides, it was considered that they are not a problem for the producers to meet. However, *national laws and regulations* were considered a concern for both the stakeholders and for some panelists. The large number of social and environmental laws and regulations in Brazil (more than 300), some conflicting, makes their application difficult. Furthermore, they evidenced that there are different interpretations of the law (there is a lack of knowledge on how to apply some laws and regulations) that contribute to non-compliance of some of them. Also, national laws, especially those related to social and labor issues, are not adapted to the rural context. As standards require compliance with national legislation, some difficulties arise in meeting this requirement. Although it is not impossible, it entails considerable investments (e.g., Forest Code compliance).

An important conclusion reached regarding this issue was that, although labor conditions have improved in recent years (State of São Paulo presents the best social indicators, the new producing states also have good indicators), this is still an issue in some regions, especially considering small independent sugarcane suppliers.

As for *biodiversity and ecosystem* requirement, it was considered that it can be accomplished with great difficulties, mainly due to the need of investments. There are no technical difficulties in meeting the requirement to preserve biodiversity, but there is lack of investment for conservation areas. The technology exists and producers should use more the information they have on ecosystems to improve biodiversity.

Another requirement that is considered difficult to comply with is related to *crop management and agrochemical use*, mainly due to differences in classifications and in the limits established by the law and by the standards. Compliance, therefore, depends on the maximum levels established by the certification schemes and also on the region and soil situation (as some soils may require more fertilizer use).

The requirements that were classified in the category "compliant with only few difficulties" are: (i) employment, wages and labor conditions; (ii) human health and safety; (iii) Soil; (iv) GHG emissions; (v) air; (vi) direct land use changes; (vii) social and environmental impact assessment; (viii): engagement and communications with stakeholders.

With respect to "employment, wages and labor conditions" and "human health and safety" requirements: it was considered that when the sugarcane production is under the control of the mills, there is no difficulty in meeting the requirements. Also, when agricultural activities are mechanized (planting and harvesting sugarcane), it is not difficult to enforce the law (given that the main difficulties are linked to employees of manual cutting). Emphasis was given once again to independent sugarcane producers (especially the small ones), who will most certainly have more compliance difficulties with these issues.

As regards the potential of *GHG emissions reductions*, there was a consensus among the stakeholders that this requirement was classified as "compliant with few difficulties". There are many studies (national and international) showing that the production of ethanol from sugar cane in Brazil reduces CHG emissions (including American studies). However, there are some measurement issues, since GHG calculations vary according to the certification scheme: RSB is more difficult than Bonsucro. However, a clear methodology to measure GHG emissions is lacking, and the main discussions are related to the inclusion of ILUC in the calculations. One of the main measurement issues is related to the data needed to prove past land use. Both Bonsucro and RSB have cut off dates related to deforestation and pasture conversion for feedstock production. However, historic data of land occupation and/or satellite images are not always available or of good quality, resulting in difficulties to assess these issues.

Concerning *"land use change"* requirement (also considered in the category of those requirements "compliant with few difficulties"), major difficulties stem from the interpretation of what degraded area is, and from the availability of data to prove that the expansion of sugarcane occurred over degraded areas. If it can be proven, there is no problem to comply with the requirement, because this area is not considered "high conservation value" area. The important variable is whether biodiversity existed at the time of planting sugarcane. For some regions (such as the Southeast) this is less of an issue, since they have more consolidated data on the past use of land. In expansion regions this will be a greater issue. However, the calculation of LUC is different according to the classification of the previous area (degraded natural pasture or degraded artificial grass). In Brazil there are a lot of artificial pastures, so the classification of whether the grass was "natural pasture" or "artificial grass" is not simple. These issues are very important, since they are decisive in the compliance with the standards.

As for "*Soil*" requirement, the stakeholder's opinion varied a lot, especially regarding the classification of vinasse disposal, which ended up being considered a requirement in the "agrochemicals" category. As for compliance, it was found that with mechanization activities, soil management is not a problem in Brazil, although compliance difficulty varies among states.

Concerning compliance with the *water* requirement, it was considered that it can be accomplished with only few difficulties. The majority of sugarcane is not irrigated and most water usage in the sugarcane fields is to extinguish the fire when it happens in the fields. It was observed that it is important to avoid the water

[3] There was not available time to discuss all 18 requirements.

[4] Ethanol plants in Brazil are usually vertically integrated through sugarcane production. The sector comprises 70 thousand independent sugarcane producers, accounting for 25% of national sugarcane production; 75% of sugarcane comes from self-supply of vertically integrated mills (mills have sugarcane fields plus processing plants).

contamination with vinasse (in this sense the limits of vinasse disposal in the soil established in the legislation must be taken into consideration).

As for the *land rights* and *waste* requirements, both were considered easy to comply with.

The majority of the stakeholders in the sucrose group agreed that the ethanol production brings positive impacts to rural development (which spreads to neighboring cities), mainly related to job creation, income generation, schooling and training improvements.

4.1.2. Technical impacts

For all dimensions (technical, financial, commercial), the stakeholder's opinion are that the impacts vary if we are talking about the short run or long run. When applicable, they can be negative in the short run and positive in the long run, as discussed below.

Considering the *technical impacts*, the sustainability requirement can cause *positive, negative or neutral impacts* on the level of technical risks the economic agents operate today (to be compliant with the requirement can imply changes in technical complexity, need for new or external technologies and/or qualified personnel, new processes impacting production capacity).

As for the stakeholder's opinions on the impact of the sustainability requirement on the *Technical Dimension*, they considered that eight requirements will cause negative impacts; seven are neutral, and one will highly negative impact the technical risk.

The reason they considered that all requirements cause negatives impacts in the short run is the necessary investments to adopt new technologies. For sugarcane suppliers, the impact is considered to be even more negative due to small production scale, lack of credit, etc.

Compliance with social and environmental legislation is not necessarily related to the adoption or development of a new technology itself (for instance mechanical agricultural activities). It may be related to the adoption of an existing technology, usually more capital intensive than the one used.

Concerning the requirements "*employment, wages and labor conditions*" and *human health and safety* the negative impacts in the short run are related to the improvements in housing, training, and health equipment. The national norm "NR-31" is very specific and requires a lot of changes. However, in the long run, the use of more advanced technologies can contribute to better work conditions, increase in labor productivity, and so on, resulting in positive impacts.

As regards the impacts of the *GHG emissions* requirement, the negative side for the producer is to find alternatives to the use of fertilizers, and to the use of fire as a detrash method of sugarcane. The positive aspect is related to the GHG calculation, for which the producers need to improve statistics. The biggest impact in the technical risk was considered the methodology for calculations of land use change.

As regards the impact of *biodiversity and Ecosystems*, it was considered that there is no technical risk, because the technology is available, and therefore, it is just a matter of implementing the technology to improve biodiversity.

In conclusion, the impacts were considered negative (or neutral) in the short run and positive in the long run.

4.1.3. Financial impacts

Considering the impacts of the sustainability requirements on the *Financial Impacts*, they were considered mostly negative in the short run. In the long run, some could be considered positive due to higher rates of return.

As mentioned before, the impact of meeting the requirements related to employment and labor conditions is negative in the short run, due to the necessity of investments. But it can be positive in the long run, because it can increase productivity. Concerning the *GHG emissions* requirement, it was considered that there is a financial risk in the short run due the adoption of the new technology. In general, negative financial impacts in the short run and positive in the long run.

4.1.4. Commercial impacts

The commercial impacts were all considered positive. The explanation for considering the impacts in the *Commercial Dimension* positive is that if the practices adopted are not in accordance with the law, it is too difficult to market or to export the product.

Customers want effective compliance; they are concerned with the regulations and sustainability criteria. Clients (for instance Coca Cola, Nestle) do not want their image linked to sugar production that has bad working conditions, environmental degradation etc.

4.2. Oil

4.2.1. Sustainability gaps

Considering the requirements analyzed by the stakeholders in the oil group discussion, it was observed that three requirements were considered in the category "easily compliant"; seven of them were considered to be "compliant with only few difficulties", and that eight of them can be "compliant with great difficulties".

The following explanations justify the option chosen for each category. In the *easily compliant* categories are the following requirements: *air, food security and waste*. Concerning the waste, it was considered that the oil feedstock produces little or no harmful waste. Co-products (cakes) have several uses (animal feed, fertilizer). Regarding food security, agricultural feedstock for bioenergy in Brazil nowadays do not compete with food production.

The requirements land rights; soil; crop management and agrochemical use; direct land use changes; social and environmental impact assessment; engagement and communications with stakeholders; economic viability and production and processing efficiency were in the "compliant with only few difficulties" category. Some observations were made regarding land use change, which was considered easy or neutral on old farming areas, but may be difficult on the expansion regions.

Concerning *social and environmental impact assessment*, it was emphasized that compliance depends on production scale: very hard to comply for smallholders; and for big farmers it is possible to comply with few difficulties. In the category "*compliant with great difficulties*" were considered: *employment, wages and labor conditions; human health and safety; GHG emissions; biodiversity and ecosystems; water; rural and social development; contractors and suppliers.* Some explanations to justify the option are: difficulties in calculating GHG, which depends on the crop, being more favorable for palm oil than for soybean. On the other hand ILUC may be greater for palm. Concerning labor conditions (human rights and labor), it may be difficult due to dependence on third parties.

4.2.2. Technical impacts

The majority of the impacts of sustainability requirements on technical risks were perceived as positive. Specifically on the impact of *Law and International Conventions*, the technical impact was considered positive because it leads to the use of more skilled workers.

Concerning the impact of the *water and Soil* requirement, the positive impact on technical risk can be explained due to the adoption of best practices (avoiding water contamination with

pesticides, erosion control). However, it was emphasized that it leads to increased costs for the business.

4.2.3. Financial impacts

Only two requirements were perceived as causing positive financial impacts: (i) crop management and agrochemical use and (ii) economic viability and production and processing efficiency). Besides those ones considered neutral or irrelevant, all other requirements (with the exception of those considered neutral or irrelevant) were considered as causing negative financial impacts, due the need of investments to accomplish them.

4.2.4. Commercial impacts

Compliance with the requirements was considered as causing positive commercial impacts. The main reasons cited were: compliance with legislation will increase costs but will have a positive impact with customers and trade; if land rights are not proven there would be problems with access to credit (negative financial impact) as well as to sell the product.

4.3. Lignocelluloses

4.3.1. Sustainability gaps

The cellulosic group comprises mainly sugarcane bagasse and forestry wood residues, although agricultural residues and grasses were also mentioned occasionally in the discussions. Given that the cellulosic feedstock selected are mostly from residues, the general evaluation is that the cellulosic group is able to comply with the majority of the sustainability requirements. Out of the 19 requirements, only one was considered possible to comply with great difficulties. The others were ranked as easily compliant and as compliant with only few difficulties.

The requirements considered as easily compliant are those in which the impacts are associated to the main product, such as sugarcane, in the case of cane bagasse and commercial forests, in the case of wood residues. The impacts associated to requirements such as crop management and agrochemical use, economic viability and production and processing efficiency, engagement and communications with stakeholders, food security, GHG emissions, rural and social development and waste are attributable to the main products, which allow the waste group to be easily compliant with requirements.

In the case of the requirements air, biodiversity and ecosystems, contractors and suppliers, direct land use changes, employment, wages and labor conditions, human health and safety, land rights, social and environmental impact assessment, Soil and water, the assessment was that, although the impacts are also attributable to the main product, the residues could not be dissociated from them.

The following explanations justify the option chosen for each requirement: (i) air: associated to the slash and burning practices of sugarcane still used in the harvesting; (ii) biodiversity and ecosystems: some regions in Brazil would have more difficulties to comply with the preservation of biodiversity and ecosystems, especially if the level of technology in production is too low or in expansion regions; (iii) contractors and suppliers: integrated value chains (sugarcane and commercial forests) were considered as easily compliant but non-integrated chains may face greater difficulties; (iv) crop management and agrochemical use: GMO varieties were not considered and the only concern is vinasse application; (v) direct land use changes: it can be an issue in *Cerrados* expansion frontier, both for sugarcane and commercial forests; (vi) economic viability and production and processing efficiency: being residues, the economic viability of production is not an issue for cane bagasse and wood residues; (vii) employment, wages and labor conditions: risks are never zero in labor conditions, although both sugarcane and commercial forests sectors have high standards; (viii) engagement and communications with stakeholders: this is a current practice in sugarcane and commercial forests sectors; (ix) food security: it can be an issue in marginal areas but it is not relevant in general; (xi) GHG emissions: even allocating some emissions in the production of the main product to the residues, GHG emissions reductions are high; (xii) human health and safety and (xiii) land rights: it varies according to the region where the feedstock is produced; (iiv) Laws and International Conventions: although not discussed in detail, the general assessment is that there are international conventions that might not be easy to comply with; (xv) rural and social development: as a general evaluation, sugarcane and commercial forests production promote rural and social development; (xvi) social and environmental impact assessment: especially in the case of independent suppliers of sugarcane to comply with social and environmental regulations is an issue; (xvii) Soil: soil conservation needs to be improved in sugarcane production; (xviii) waste: easily compliant because wastes in sugarcane and commercial forest production have value; (xix) water: assuming production without irrigation, which is the majority of the cases for sugarcane and commercial forests, water usage is not an issue. However, water yield is a topic to be monitored in situations with certain types of land use changes.

4.3.2. Technical impacts

Given that the feedstocks for cellulosic biofuels are residues, all impacts of sustainability requirements on technical risks were perceived as positive and highly positive. The assessment is that complying with the sustainability requirements helps to reduce technical risks or helps to reinforce cellulosic biofuel as a strong alternative for renewable fuels in comparison with other sources of renewables.

4.3.3. Financial impacts

The criteria used to analyze the financial impacts was to separate impacts from sustainability requirements in two groups: one with the capacity to aggregate value to the final product and a second one that brings only additional costs without necessarily aggregating more value to the final product.

Based on those criteria, the requirements considered as only aggregating costs were employment, wages and labor conditions, Laws and international conventions, and social and environmental impact assessment.

4.3.4. Commercial impacts

Following similar criteria used in technical and financial risks, the impact of the sustainability requirement was considered positive if it is able to aggregate value from a marketing perspective. Based on this criterion, all sustainability requirements were considered positive and highly positive.

4.4. Waste

4.4.1. Sustainability gaps

Differently from the others feedstock in which the sustainability requirements were assessed from the production perspective (for instance forest and agriculture)the waste group assessment was more related to the process of collecting, cleaning and preparing the types of wastes (flue gas, used cooking oil, municipal solid waste and animal fat), as well as the refining process.

The majority of the sustainability requirements were considered as easily compliant or compliant with a few difficulties. The easily compliant requirements are those unrelated to the supply of wastes. Waste supply is not associated to the use of land or does

not use land as an input and, therefore, wastes are able to comply with any requirement associated to land use changes, land rights, biodiversity, food security and soil conservation.

With respect to the other requirements for which wastes can comply with only few difficulties, the explanations are case by case. Air and water are inputs for the waste supply chain and process and, depending on the type of the waste to be processed, those inputs can be intensively used. MSW and flue gas use more water than use cooking oil and animal fat. Waste processes can also generate products that need treatment and, therefore, some difficulties may appear to comply with the requirement.

On the *economic viability requirement*, some processes still need to be more efficient. Waste collection on landfills faces strong labor informality in Brazil. Although there is space for improvement, big cities would probably be better positioned than small cities. There are large communities working in waste collection and to develop a mechanism to communicate with the stakeholders of those communities can be a challenge.

In the case of MSW, human health and safety needs strong improvements, although for other wastes types it is easy to comply with the requirements. Social development may be improved if wastes are used for producing fuels, however the level of informality in some cases may be a limiting factor.

In *social and environmental impact assessment* the perception is that compliance can be easier than other feedstock, although transaction costs to produce an impact assessment are high in Brazil.

The compliance with GHG emissions requirements depends on the waste type. Some processes are extremely energy intensive, which can undermine GHG emissions reductions. Flue gas needs hydrogen and can be considered very hard to be compliant. MSW, the biodegradable portion, can comply with great difficulties. Tallow and used cooking oil can comply more easily than the others but also depend on specific situations.

Wastes supply chains, in general, have several middlemen and intermediary agents, making traceability very hard to be implemented. For that reason, it was considered as very hard to be compliant.

4.4.2. Technical impacts

In terms of the impacts on the technical process, the majority of the requirements were considered as neutral, or irrelevant or not applicable. The requirements considered neutral are almost the same considered neutral in the previous section plus the ones considered easily compliant because they are not related to waste supply. In the case of requirements ranked with positive impacts, the main criteria was that the use of the waste for processing jet biofuels will improve the capacity of the industry to comply with the requirement and, therefore, reduce technical risks.

In several other requirements, the risks are different among the wastes types (MSW, tallow, flue gas and used cooking oil) and depend on the process. In general, those sustainability requirements are expected to have highly positive or positive impacts.

4.4.3. Financial impacts

The requirements considered as neutral or irrelevant or not applicable are very similar to the previous section and, therefore, the reasons are the same: the requirement is not related to the supply of the waste.

Engagement with stakeholders, GHG emissions, human health and safety, Law and international conventions and social and environmental impact assessment were considered as having positive impacts on financial risks. On the other hand, requirements perceived as directly associated to production costs, such as employment, wages and labor conditions, rural and social development and Waste treatment, were considered as increasing financial risks.

In the case of *water* and *air*, additional treatments may increase investment costs, but more efficient processes can save the use of the resource. For that reason, the impacts can be both positive and negative.

4.4.4. Commercial impacts

The assessment for commercial risks is different from technical and financial risks. The majority of the requirements were considered highly positive or positive. The main perception is that complying with sustainability requirements creates value in the market for fuels from wastes, acting as an incentive for wastes value chain to adopt sustainability standards as a commercial strategy. The conclusion is that fuels from wastes are sustainable from a marketing perspective.

An overall view of the evaluation of the degree of difficulty to meet requirement for the four groups of feedstocks is available in Fig. A.1, and the feedstock compliance to sustainability requirements, laws and regulations can be found in Fig. A.2.

5. Discussion and conclusions

Sustainability is a fundamental topic to be addressed in the establishment of a market for the production and use of jet biofuels in Brazil. Although there are important differences among the four groups of feedstock, some general common considerations can be made regarding biofuels production and to the gaps of complying with sustainability requirements.

Concerning the social area, the main positive impacts are the high potential of job creation and income generation, and the positive impacts on regional development. As for the sustainability requirements gaps, the factors that make compliance more difficult were considered: the great number of laws and rules, sometimes more strict than sustainability standards; different interpretations and the lack of knowledge on how to apply some laws; labor laws not adapted to the rural context. It was also noted that there is a need for qualification and capacitation of workers.

As for the Environmental Aspects, the positive impact regarding compliance with the requirement is related to Reduction in GHG emissions compared to fossil fuels, especially in the sucrose and cellulosic groups, although there are still some difficulties with GHG calculation and data. Concerning the debate food versus fuel, it is not such an important issue in Brazil, since there is enough available land for the production of biofuels from agricultural feedstock. The great number of environmental laws and rules (sometimes more strict than sustainability standards) and legal uncertainty (changes in the Forest Code, law regulating the conditions for Foreign Investors) are considered difficulties to comply with the legal requirement.

It was considered that it is possible to comply with national and international rules and norms, but that it requires investment. In general terms, small and independent producers have more difficulty to comply with the requirements. In addition, the extensive Brazilian territory makes it difficult to enforce some laws.

The need of a clear price policy for fuels was emphasized, in order to make the production sustainable economically and to attract private investments and to promote the use of jet biofuels.

Appendix A

See Fig. A1 and A2.

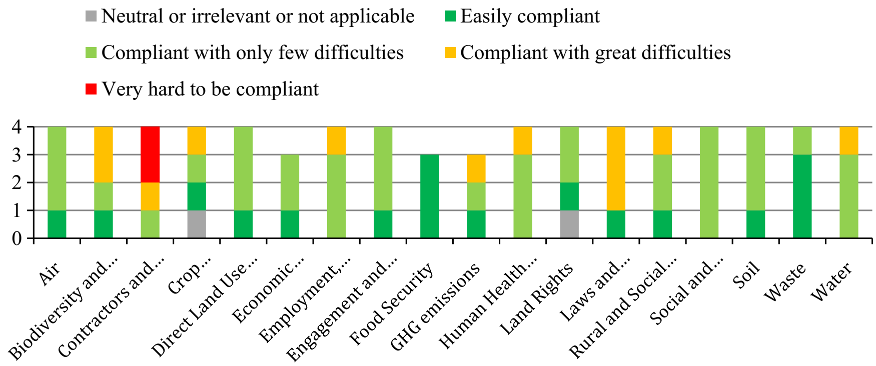

Fig. A.1. Overall evaluation of the degree of difficulty to meet requirement.

Feedstock Group	Social	Environmental	Economic
Sucrose/starch	• Great number of laws and regulations; different interpretations and lack of knowledge on how to apply laws; small and/or independent producers have more difficulty to comply; labor laws not adapted to the rural context; Personal Protective Equipment not adapted to rural workers; although labor conditions have improved, this is still an issue in some regions, especially with independent suppliers; difficulties with documentation on land rights, especially in some regions; • Rural development: job creation, income generation, improve schooling and training	• The compliance of some requirements varies among regions and soil situation • Main difficulties related to: (i) biodiversity and ecosystem; (ii) crop management • Direct Land Use Change: compliance different among regions (e.g. good in São Paulo and Minas Gerais, but other states may have lack of data to prove that the area was a degraded area) • Vinasse: some states have legislation, others don't. Depending on the standard, criteria can be easy or difficult to comply with.	• Standards are focused on production efficiency of feedstock; lack of data on costs of jet biofuels since there is no scale production in Brazil. Experimental production has taken place, but the costs are unknown. Price policies must be defined and should consider the positive externalities of biofuels.
Oil-bearing	• Human rights and labor issues: Difficult to depend on third parties; Compliance with the laws will increase costs but will have a positive impact with customers; If land rights are not proven there would be problems with access to credit (financial) as well as to market the product; Small producers may have more difficulty to comply;	• Compliance with the laws will increase costs but will have a positive impact with customers; Small producers may have more difficulty to comply; Difficulties with calculating GHG. Depends also on crop. More favorable for palm oil than for soybean. On the other hand ILUC may be greater for palm; Better farming practices may have a positive technical impact but there are several unknowns on this topic; LUC: Easy or neutral on old farming areas but may be difficult on the frontiers; may be difficult for palm oil; Great difficulties for expansion of feedstock production; Brazilian feedstocks for bioenergy are not competing with food. There is a positive impact for clients, therefore improves commercial impacts. Food versus fuel may be a problem in the future.	• Standards are focused on production efficiency of feedstocks; lack of data on costs of jet biofuels since there is no scale production in Brazil. Experimental production has taken place, but the costs are unknown. Price policies must be defined and should consider the positive externalities of biofuels.
Cellulosic	• Compliance with most of the laws depends on the region; Land rights: there are regions in which this may be a larger issue; • Contractors and Suppliers: sustainability compliance would be easier in integrated value chains such as sugarcane and planted forests and systems that are able to generate by-products than systems dedicated to one product; integrated systems have different results than non-integrated; issue of equivalence and overlapping of regulations and requirements, especially since we have two layers (national and international)	• Compliance with most of the laws and standards is expected to be achievable because the impacts are attributable to the main product; GHG emissions calculation is a complex issue, depends on the feedstock, the process, local conditions, etc; Biodiversity: in some regions and feedstocks the compliance might be more difficult; assuming that water usage is not an issue compliance is easy; Water yield can be an issue depending the land use change; Biological control and chemical control ; • LUC: Can be an issue for future expansion in the Cerrados. Compared to other feedstocks cellulosic is creating value and positive impacts; issue of equivalence and overlapping of regulations and requirements, especially since there are two layers (national and international)	• Standards are focused on production efficiency of feedstocks; lack of data on costs of jet biofuels since there is no scale production in Brazil. Experimental production has taken place, but the costs are unknown. Price policies must be defined and should consider the positive externalities of biofuels.
Wastes	• There is potential for conflicting laws. Careful not to inhibit process of developing solutions; informality of labor for waste collection and landfills. Room for improvement. May not be as easy to compliant. In the case of big cities, it will probably be easy, but in smaller cities it might be harder; Improve the safety of employees. Making conditions of workers better; Social Development: Infrastructure development, jobs. Consider financial difficulties that are involved. Different financial options that do not result in the same amount of social development	• There is potential for conflicting laws. Careful not to inhibit process of developing solutions; GHG emissions: some processes are extremely energy intensive. Compliance varies among processes (easy to comply to difficult to comply) ; Increases technical complexity and pushes innovation. Maybe not very much of a margin to increases GHG reductions. Biodiversity: Easily compliant because there are no problems related to land. • Water: Processes with high water demand (cooking oil); animal fat: comply with great difficulties; Water pollution must be addressed.	• Standards are focused on production efficiency of feedstocks; lack of data on costs of jet biofuels since there is no scale production in Brazil. Experimental production has taken place, but the costs are unknown so far. Price policies must be defined and should consider the positive externalities of biofuels.

Fig. A.2. Feedstock compliance to sustainability requirements, laws and regulations.

References

[1] Marsh G. Biofuels: aviation alternative? Renewable Energy Focus 2008;9(4):48–51.

[2] Sgouridis S. Are we on course for a sustainable biofuel-based aviation future? Biofuels 2012;3(3):243–6.

[3] IPCC, 2007. Fourth Assessment Report: Climate Change 2007 (AR4). Available online: 〈http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#.UYP1UrXvuSo〉.

[4] ATAG. Facts and figures—air transport. Available online: 〈http://www.atag.org/facts-and-figures.html〉; 2012.

[5] Ludeke-Freund F, Walmsley D, Plath M, Wreesmann J, Klein AM. Sustainable plant oil production for aviation fuels: assessment challenges and consequences for new feedstock concepts. Sustainability Acc Manage Policy J 2012;3(2):186–217.

[6] Flight Path to Aviation Biofuels in Brazil: Action Plan. São Paulo. Boeing, Embraer, Fapesp, UNICAMP; 2013.

[7] CGEE. Sustainability of sugarcane bioenergy. DF: Brasília; 2012.

[8] Goldemberg J. The Brazilian biofuels industry. Biotechnology for Biofuels 2008;I:6.

[9] Goldemberg J, Coelho ST, Guardabassi P. The Sustainability of ethanol production from sugarcane. Energy Policy 2008;36(6):2086–97.

[10] Nassar AM, Harfuch L, Moreira MMR, Bachion L, Antoniazzi LB, Lima RC. Simulating land use and agriculture expansion in Brazil: food, energy, agro-industrial and environmental impacts. BIOEN–FAPESP program 2011:16 (Project number 2008/56156-0. Page).

[11] Tilman D, Socolow R, Foley JA, Hill J, Larson E, Lynd L, et al. Beneficial biofuels–the food, energy, and environment trilemma. Science 2009;325:270–1.

[12] Bauen A, Howes J, Bertuccioli L, Chudziak C. Review of the potential for biofuels in aviation. E4Tech 2009 (Available online).

[13] Del Rio P, Burgillo M. Assessing the impact of renewable energy deployment on local sustainability: towards a theoretical framework. Renewable Sustainable Energy Rev 2008;12(5):1325–44.

[14] United Nations. Our common future. World Commission on Environment and Development. Available online: 〈http://conspect.nl/pdf/Our_Common_Future-Brundtland_Report_1987.pdf〉; 1987.

[15] Goldemberg, J. An historical account of bioenergy production in Brazil. Campos do Jordão, August 14th. 2011, RSB, ISCC, Greenergy, Bonsucro; 2011.

[16] Nassar AM, Moura PT, Granço G, Harfuch L. Benchmark of cane-derived renewable jet fuel against major sustainability standards 2012.